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EMPIRICAL REDUCTION IN POTENTIAL USER POPULATION AS THE RESULT OF IMPOSED MULTIVARIATE ANTHROPOMETRIC LIMITS

LT William F. Moroney, MSC, USN, and Margaret J. Smith

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Workspaces, from desk top consoles to aircraft cockpits, have traditionally been designed to accommodate the "average man" (50th percentile on all anthropometric features) or individuals included within some specified range about the median (5th through 95th percentiles; 1st through 99th percentiles, etc.) Manufacturers usually design equipment such that clearances, reach distances, and other critical measurements will accommodate individuals having all their anthropometric features in the 5th to 95th percentile range. A more stringent requirement, currently in effect for aircraft cockpits, specifies accommodation of individuals with anthropometric features ranging from the 3rd to the 98th percentiles. The classical solution to these design requirements has been to construct mannequins or engineering sketches with the anthropometric features of a "3rd, 5th, 50th, 95th, or 98th percentile man."

The establishment of these critical limits (3rd, 5th, 95th, and 98th percentiles) assumes implicitly that if only the "less than 5th" and "greater than 95th" percentile individuals are not accommodated then only 10 per cent of the available sample will be excluded. Given this same assumption, if the 3rd and 98th percentile limits are selected, only 5 per cent of the available sample should be eliminated. Such a procedure presupposes that those individuals with an anthropometric measurement beyond the established range on one anthropometric characteristic will be the same individuals who fall outside the established range on all other anthropometric features. This supposition is demonstrably false to the extent that multiple anthropometric features are involved in the design of workspaces.

Data describing thirteen, cockpit related, anthropometric features of 1547 naval aviator personnel were examined. Two analyses were performed on these data. In the first analysis individuals not included within the 5th percentile to the 95th percentile critical limits on any of the 13 features cited above were eliminated. After all 13 eliminations had been completed, 814 (52.6%) of the original 1547 had been excluded. In the second analysis, the critical limits were established at the 3rd and 98th percentiles, and 499 (32.2%) of the personnel were excluded. Thus, where one might have expected only 10 per cent of the population to have been excluded, 52.6 per cent were excluded, and where only 5 per cent theoretically might have been excluded, 32.2 per cent were excluded. This seeming discrepancy may be attributed to the intercorrelations existing between the 13 variables. The importance of considering the relationship between anthropometric features in determining anthropometric compatibility is discussed. The preparation of bivariate data, which is not variable specific but which could be used when the correlation between athropometric features is known, is proposed.

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SUMMARY PAGE

THE PROBLEM

Workspaces, from desk top consoles to aircraft cockpits, have traditionally been designed to accommodate the "average man" (50th percentile on all anthropometric features) or individuals included within some specified range about the median (5th through 95th percentiles; 1st through 99th percentiles, etc.). Manufacturers usually design equipment such that clearances, reach distances, and other critical measurements will accommodate individuals having all their anthropometric features in the 5th to 95th percentile range. A more stringent requirement, currently in effect for aircraft cockpits, specifies accommodation of individuals with anthropometric features ranging from the 3rd to the 98th percentiles. The classical solution to these design requirements has been to construct mannequins or engineering sketches with the anthropometric features of a "3rd, 5th, 50th, 95th, or 98th percentile man."

The establishment of these critical limits (3rd, 5th, 95th, 98th percentiles) assumes implicitly that if only the "less than 5th" and "greater than 95th" percentile individuals are not accommodated, then only 10 per cent of the available sample will be excluded. Given this same assumption, if the 3rd and 98th percentile limits are selected, only 5 per cent of the available sample should be eliminated. Such a procedure presupposes that those individuals with an anthropometric measurement beyond the established range on one anthropometric characteristic will be the same individuals who fall outside the established range on all other anthropometric features. This supposition is demonstrably false to the extent that multiple anthropometric features are involved in the design of workspaces.

FINDINGS

Data describing thirteen, cockpit related, anthropometric features of 1547 naval aviator personnel were examined. Two analyses were performed on these data. In the first analysis individuals not included within the 5th percentile to 95th percentile critical limits on any of the 13 features cited above were eliminated. After all 13 eliminations had been completed, 814 (52.6%) of the original 1547 naval aviator personnel had been excluded. In the second analysis, the critical limits were established at the 3rd and 98th percentiles, and 499 (32.2%) of the personnel were excluded. Thus, where one might have expected only 10 per cent of the population to have been excluded, 52.6 per cent were excluded, and where only 5 per cent theoretically might have been excluded, 32.2 per cent were excluded. This seeming discrepancy may be attributed to the intercorrelations existing between the 13 variables. The importance of considering the relationship between anthropometric features in determining anthropometric compatibility is discussed. The preparation of bivariate data, which is not variable specific but which could be used when the correlation between anthropometric features is known, is proposed.

INTRODUCTION

Workspaces, from desk top consoles to aircraft cockpits, have traditionally (1, 6, 7, 14) been designed to accommodate the "average man" (50th percentile on all anthropometric features) or individuals included within some specified range about the median (5th through 95th percentiles; 1st through 99th percentiles, etc.). Manufacturers usually design equipment such that clearances, distances, reaches, and other critical measurements will accommodate individuals having all their anthropometric features in the 5th to 95th percentile range. A more stringent requirement, currently in effect for aircraft cockpits, specifies accommodation of individuals with anthropometric features ranging from the 3rd to the 98th percentiles. The classical solution to these design requirements has been to construct mannequins or engineering sketches with the anthropometric features of a "3rd, 5th, 50th, 95th, or 98th percentile man."

The establishment of these critical limits (3rd, 5th, 95th, 98th percentiles) assumes implicitly that if only the "less than 5th" and "greater than 95th" percentile individuals are not accommodated, then only 10 per cent of the available sample will be excluded. Given this same assumption, if the 3rd and 98th percentile limits are selected, only 5 per cent of the available sample should be eliminated. Such a procedure presupposes that those individuals with an anthropometric measurement beyond the established range on one anthropometric characteristic will be the same individuals who fall outside the established range on all other anthropometric features. This supposition is demonstrably false to the extent that multiple anthropometric features are involved in the design of workspaces. The exclusion of 10 per cent of the population on each dimension will result in the exclusion of a substantially larger percentage when the total workspace is considered. The implications of excluding significant proportions of the user population from safe and efficient use of a workspace increase in magnitude as the number of dimensions to be considered increases. In a "one-dimensional" space, clearances based on the average man will create problems for individuals exceeding the stature of the average man (50 per cent of the population). Similarly, locating a control at the outer edge of the average man's reach envelope will prevent shorter-limbed individuals from reaching the particular control (again 50 per cent of the population). When more than one anthropometric feature is considered the complexity of the problem increases. Daniels (2) broadened the definition of average to include dimensions within plus or minus three-tenths of a standard deviation of the mean value of a particular anthropometric feature (approximately the middle 25 - 30 per cent of the sample). After an examination of a sample of 4,063 U. S. Air Force aviation personnel, it was determined that none of the individuals were average on each of the 10 anthropometric features related to clothing design. Moroney (8) demonstrated that given a correlation of 0.39 between two variables, if all individuals falling below the 5th percentile on both variables were excluded from the user population, then not five but approximately ten per cent of the population were excluded.

This paper examines the impact of using preestablished critical limits (anthropometric percentiles) as the basis of excluding individuals from the user population. A series of 13, workspace related, anthropometric features are used to define "included" or "excluded" individuals. The effect of the correlation, between anthropometric features, on the number of personnel excluded will be discussed.

PROCEDURE

In 1964, Gifford, Provost, and Lazo (3) examined 96 anthropometric features of 1549 naval aviation personnel. These data were also used in this study; 13 of the 96 anthropometric features were selected because of their particular relevance to cockpit design. These features are also appropriate for use in automobile or console design. The thirteen features were: sitting height; eye-height, sitting; shoulder-height, sitting; functional reach; bideltoid diameter; buttock-knee length; buttock-popliteal length; hip-breadth, sitting; knee-height, sitting; popliteal-height, sitting; shoulder-elbow length; forearm-hand length; and elbow rest height. Definitions of these features are included in Appendix A.

Two members of the original sample of 1,549 members were not included in the data analysis because of missing data. Additionally, new descriptive statistics were obtained for all thirteen variables and are reasonably similar to those reported by Gifford et al. (3) Critical limits were determined for the 3rd, 5th, 95th, and 98th percentiles for each variable and are listed in Table I in the sequence examined. Individuals not included within the critical limits of any one of the 13 anthropometric features were excluded from analysis of subsequent features. Two analyses were performed; the critical limits for the first analysis were the 5th and 95th percentiles and for the second analysis the 3rd and 98th percentiles. The intent of these analyses was to determine the actual percentage of the population excluded when 10 per cent (5th - 95th) or 5 per cent (3rd - 98th) were eliminated on each of 13 features. In addition, a record of the number of variables on which each subject failed to attain or exceeded the critical value was obtained. The correlation between variables was also calculated.

Table I

Limits* Established for Each Anthropometric Feature

Anthropometric Feature	Percentiles			
	3rd	5th	95th	98th
Sitting Height	34.0	34.2	38.3	38.9
Eye Height, Sitting	29.4	29.7	33.6	34.2
Shoulder Height, Sitting	21.8	22.0	25.5	26.0
Functional Reach	29.1	29.3	34.0	34.7
Bideltoid Diameter	17.0	17.3	20.3	20.7
Buttock-Knee Length, Sitting	22.3	22.5	25.8	26.2
Buttock-Popliteal Length, Sitting	18.0	18.2	21.5	21.9
Hip Breadth, Sitting	12.9	13.1	15.9	16.3
Knee Height, Sitting	20.1	20.3	23.5	23.9
Popliteal Height, Sitting	15.7	15.9	18.8	19.1
Shoulder-Elbow Length	13.3	13.4	15.6	15.9
Forearm-Hand Length	17.7	17.9	20.4	20.6
Elbow Rest Height	7.4	7.6	10.9	11.4

*All values are in inches.

RESULTS AND DISCUSSIONS

Only 47.38 per cent of the sample used in this investigation had anthropometric features which fell within the critical limits for the 5th - 95th percentiles on all of the 13 variables (Fig. 1). Considerably more are included when the critical limits for the 3rd - 98th percentiles are used--67.74 per cent (Fig. 2). Thus, 52.62 per cent and 32.26 per cent of the potential user population would be excluded if the critical limits for the 5th - 95th and 3rd - 98th percentiles, respectively, were stringently applied in workspace and equipment design.

Tables II and III provide more specific data on the number and per cent eliminated when the 5th - 95th percentile, and 3rd - 98th percentile limits were selected. An examination of Table II reveals that 152 individuals (9.82 per cent of the sample) had features which did not attain or which exceeded the 5th - 95th percentile limits for sitting height. The anthropometric feature eye height, sitting, eliminated 57 additional individuals (3.68 per cent of the original sample of 1,547). When all data had been tested against the thirteen critical limits, 52.62 per cent of the population had been excluded. A similar pattern appeared when the 3rd and 98th percentile limits were utilized. However, as might be expected a lesser percentage of the sample were excluded--32.26 per cent.

In Table II, 9.82 per cent of the sample did not satisfy the sitting height criterion. However, only 3.68 and 3.62 per cent of the total sample were excluded on the next two cuts (eye height, sitting; and shoulder height, sitting; respectively). The exclusion of such a relatively small percentage of the sample suggests that the latter two variables are not independent of the first variable. An examination of Table IV reveals that reasonably high intercorrelations exist between the three variables. However, the correlations between the first three variables and functional reach are fairly low. These low correlations explain why functional reach excludes a unique 7.11 per cent of the sample. An analogous situation exists for bideltoid diameter and to a lesser extent buttock-knee length. Subsequent anthropometric features are less independent and account for proportionately less exclusions. This rationale is equally applicable to the data contained in Table III.

Thus, the low intercorrelations between certain variables account for the large number of personnel excluded. In general, moderate to relatively low intercorrelations exist between anthropometric features. Indeed, only 11 of the 78 intercorrelations in Table IV exceed 0.70. In a separate report (9) the intercorrelations between 96 anthropometric features taken on 1,547 naval aviation personnel were examined and it was determined that only 4.21 per cent of the intercorrelations exceeded 0.70.

A statement of the number of variables on which an individual exceeded or failed to attain the critical value is contained in Table V. Most of the individuals not satisfying the criterion were excluded on the basis of one or two variables. Comparatively, few individuals exceeded the critical limits on each of six or more variables.

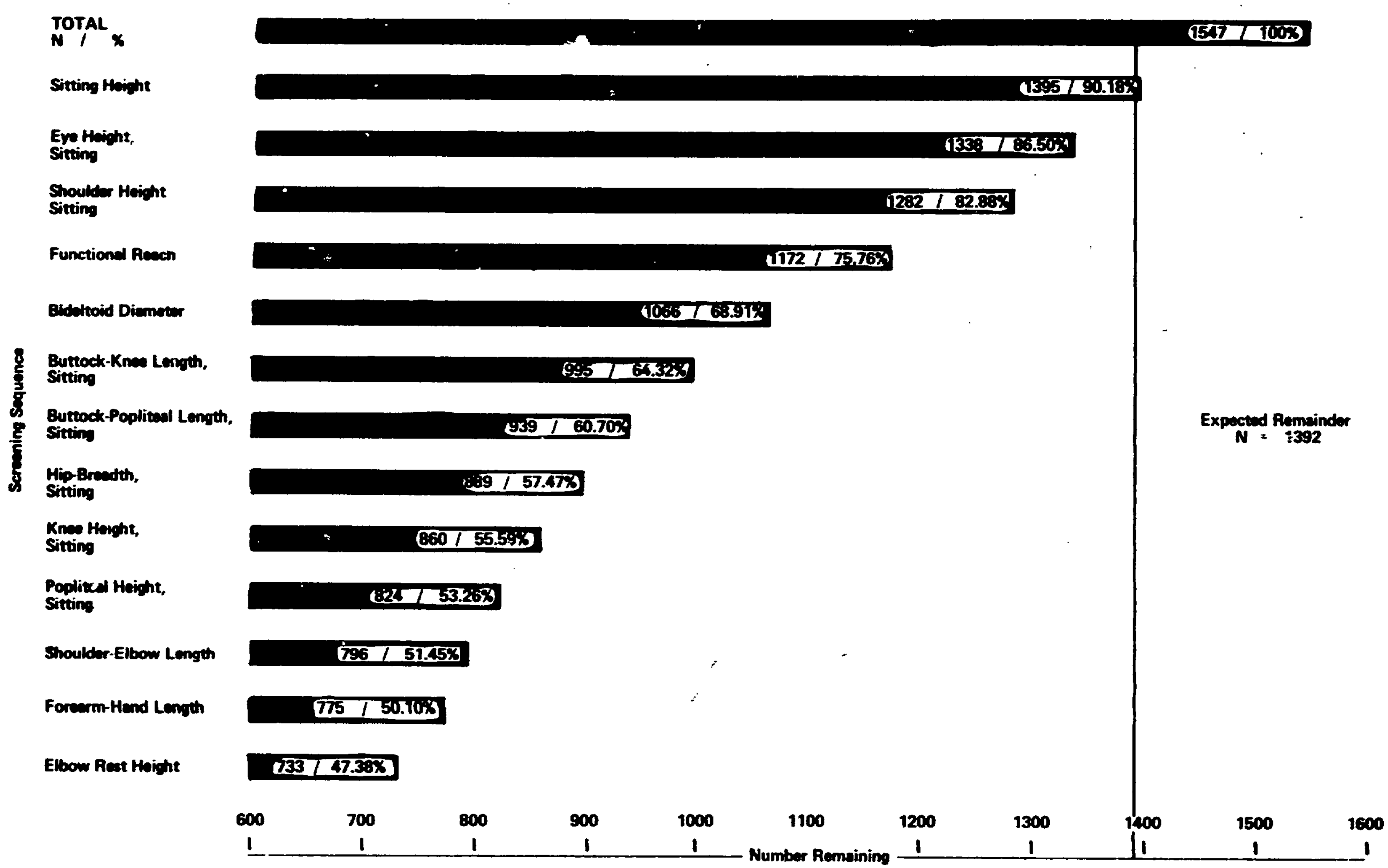

Fig. 1. Number and per cent of personnel remaining after all individuals with anthropometric features less than the 5th or greater than the 95th percentile had been excluded.

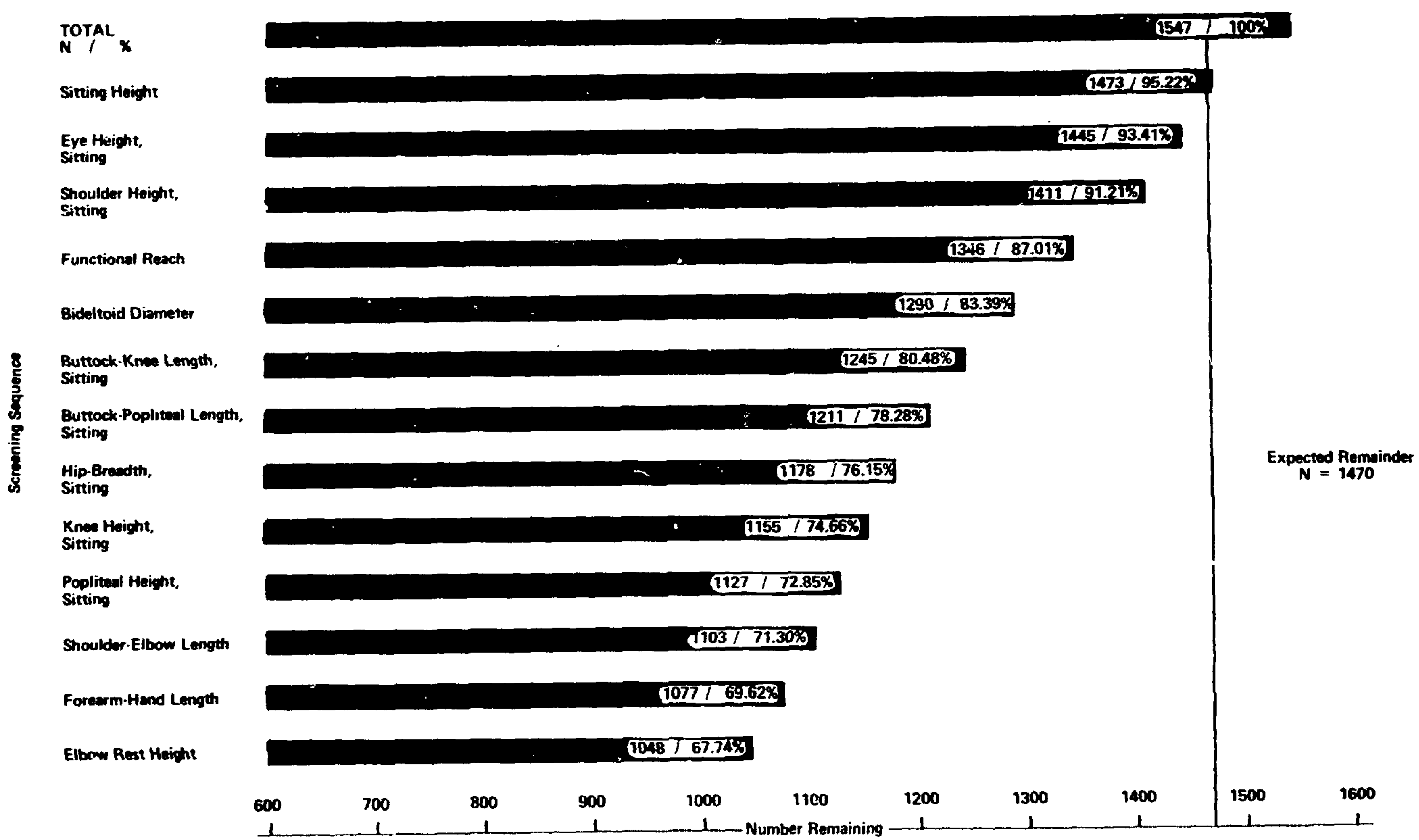

Fig. 2. Number and per cent of personnel remaining after all individuals with anthropometric features less than the 3rd or greater than the 98th percentile had been excluded.

Table II

Number and Per Cent of Personnel Excluded When the 5th and 95th Percentile Critical Limits are Utilized as Screening Values

Screening Sequence	Number Excluded	Per Cent of Total Sample Excluded
1. Sitting Height	152	9.82
2. Eye Height, Sitting	57	3.68
3. Shoulder Height, Sitting	56	3.62
4. Functional Reach	110	7.11
5. Bideltoid Diameter	106	6.85
6. Buttock-Knee Length, Sitting	71	4.59
7. Buttock-Popliteal Length, Sitting	56	3.62
8. Hip Breadth, Sitting	50	3.23
9. Knee Height, Sitting	29	1.88
10. Popliteal Height, Sitting	36	2.33
11. Shoulder-Elbow Length	28	1.81
12. Forearm-Hand Length	24	1.36
13. Elbow Rest Height	42	2.72
Total	814	52.62

Table III

Number and Per Cent of Personnel Excluded When the 3rd and 98th Percentile Critical Limits are Utilized as Screening Values

Screening Sequence	Number Excluded	Per Cent of Total Sample Excluded
1. Sitting Height	74	4.78
2. Eye Height, Sitting	28	1.81
3. Shoulder Height, Sitting	34	2.20
4. Functional Reach	65	4.20
5. Bideltoid Diameter	56	3.62
6. Buttock-Knee Length, Sitting	45	2.91
7. Buttock-Popliteal Length, Sitting	34	2.20
8. Hip Breadth, Sitting	33	2.13
9. Knee Height, Sitting	23	1.49
10. Popliteal Height, Sitting	28	1.81
11. Shoulder-Elbow Length	24	1.55
12. Forearm-Hand Length	26	1.68
13. Elbow Rest Height	29	1.88
Total	499	32.26

Table IV

Intercorrelations Between Thirteen Anthropometric Features

	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Sitting Height		.93	.79	.38	.26	.38	.31	.32	.45	.44	.41	.47	.56
2. Eye Height, Sitting			.79	.36	.29	.39	.32	.33	.47	.40	.43	.44	.54
3. Shoulder Height, Sitting				.28	.23	.40	.31	.38	.46	.34	.48	.40	.73
4. Functional Reach					.26	.59	.52	.22	.60	.63	.56	.73	-.08
5. Bideltoid Diameter						.44	.32	.58	.38	.14	.31	.28	.01
6. Buttock-Knee Length, Sitting							.81	.52	.78	.62	.68	.66	-.05
7. Buttock-Popliteal Length, Sitting								.39	.67	.56	.57	.55	-.06
8. Hip Breadth, Sitting									.42	.13	.34	.28	.17
9. Knee Height, Sitting										.78	.75	.74	-.05
10. Popliteal Height, Sitting											.59	.74	-.04
11. Shoulder-Elbow Length												.67	-.15
12. Forearm-Hand Length													-.03
13. Elbow Rest Height													

Table V

Number and Per Cent of Individuals Excluded and Number of Variables on Which They Were Excluded

Number of Variables on Which an Individual Fell Outside Critical Limits	Number and Per Cent of Individuals Falling Outside Critical Limits — Percentile Limits: 5th - 95th		3rd - 98th	
	N	%*	N	%*
1	355	22.95	256	16.55
2	168	10.86	127	8.21
3	107	6.91	49	3.17
4	72	4.65	41	2.65
5	52	3.36	11	.71
6	32	2.07	5	.32
7	15	.97	5	.32
8	6	.39	3	.19
9	3	.19	2	.13
10	2	.13		
11	2	.13		

*Per cent based on total sample size of 1547.

CONCLUSIONS AND RECOMMENDATIONS

To design workspaces without an awareness of the interaction between anthropometric variables ultimately leads to a considerable reduction in the size of the accommodated population. If a designer is to determine the per cent of his potential user population which will be excluded by his design decision, additional information is needed. Since the problem arises from the relationship between variables, it was felt that perhaps correlational techniques might also contribute to a solution. In the past, a specific bivariate table (8, 11) was prepared for the two anthropometric variables of interest. Unfortunately, the number of bivariate tables which can be produced is limited only by the number of anthropometric features for which data are available and by one's needs at a particular time. An alternate solution would be to prepare bivariate data which is not variable specific, but which could be used when the correlation between anthropometric features is known. To achieve this end three reports have been prepared. The first report (9) contains the correlations between 96 anthropometric variables based on data collected on 1,547 naval aviation personnel. Having obtained the correlation between the anthropometric variables of interest, the designer enters the appropriate table or figure contained in the second (12) and third (13) reports, respectively. These reports contain cell entries for bivariate normal frequency distributions with correlation values from 0.00 to 0.95 in increments of 0.05 and from 0.96 to 1.00 in increments of 0.01. By using the data as presented, or interpolating for the exact value, a designer can determine the per cent of the population excluded by the critical limits established for both variables. Use of the materials contained in the reports cited above provides needed information when considering bivariates. Multivariate distributions are not amenable to such a treatment. Perhaps the only solution, other than test-fitting the entire user population, may be found in the development of variable sized mathematical man-machine models (5, 10).

REFERENCES

1. Damon, A., Stoudt, H. W., and McFarland, R. A. *The Human Body in Equipment Design.* Cambridge, Mass.: Harvard University Press, 1966.

2. Daniels, G. S. The average man. Technical Note NCRD 53-7. Wright-Patterson Air Force Base, Ohio: Aero Medical Laboratory, 1952.

3. Gifford, E., Provost, J., and Lazo, J. Anthropometry of naval aviators--1964. NAEC-ACEL 533. Philadelphia, Pa.: Naval Air Engineering Center, Air Crew Equipment Laboratory, 1965. (AD 626 332).

4. Hertberg, H. T. E., Daniels, G. S., and Churchill, E. Anthropometry of flying personnel--1950. WADC TR 52-321. Wright-Patterson Air Force Base, Ohio: Wright Air Development Center, 1954. (AD 47953).

5. Kilpatrick, K. E., A biokinematic model for workspace design. *Human Factors, 14:*237-247, 1972.

6. McCormick, E. J. *Human Factors Engineering.* New York: McGraw-Hill, 1964.

7. Morgan, C. T., Cook, J. S., Chapanis, A., and Lund, M. W. *Human Engineering Guide to Equipment Design.* New York: McGraw-Hill, 1963.

8. Moroney, W. F. Selected bivariate distributions describing a sample of naval aviators--1964. NAMRL-1130. Pensacola, Fla.: Naval Aerospace Medical Research Laboratory, 1971.

9. Moroney, W. F., and Smith, M. J. Intercorrelations and selected descriptive statistics of 96 anthropometric variables based on 1547 naval aviation personnel. NAMRL-1154. Pensacola, Fla.: Naval Aerospace Medical Research Laboratory, 1972.

10. Ryan, P. W., Cockpit geometry evaluation, Phase II. A Final Report, Volume I--Program Description and Summary. JANAIR Report 700201. Seattle, Washington: The Boeing Company, 1970.

11. Ryan, P. W. Cockpit geometry evaluation, Phase II, Final Report, Volume II--Program Description and Summary. JANAIR Report, 700202. Seattle, Washington: The Boeing Company, 1970.

12. Smith, M. J., and Moroney, W. F. Bivariate normal frequency distributions--Part I: Tables of per cent excluded by restricting either or both variate distributions and procedures for applied use. NAMRL-1166. Pensacola, Fla.: Naval Aerospace Medical Research Laboratory, 1972.

13. Smith, M. J., and Moroney, W. F., Bivariate normal frequency distributions--Part II: Figures of percentages by cells. NAMRL-1167. Pensacola, Fla.: Naval Aerospace Medical Research Laboratory, 1972.

14. Woodson, W. E., and Conover, D. W. *Human Engineering Guide for Equipment Designers.* Los Angeles: University of California Press, 1966.

APPENDIX A

DEFINITIONS* OF ANTHROPOMETRIC FEATURES

*These definitions were derived from the definitions presented in reports by Hertzberg, Daniels, and Churchill (4) and by Damon, Stoudt, and McFarland (1). These reports also contain illustrations of the features described in this appendix.

Bideltoid Diameter is the horizontal distance between the maximum lateral protrusion of the deltoid muscles. This measurement is taken with the subject sitting erect, upper arms hanging at his sides, and his forearms extended horizontally.

Buttock-Knee Length is the horizontal distance from the rearmost point of the right buttock to the front of the kneecap. The measurement is taken with the subject seated erect and his feet resting on a surface so that his knees are bent at about right angles.

Buttock-Popliteal Length is the horizontal distance from the rearmost point on the buttocks to the back of the lower leg at the knee. The measurement is taken with the subject seated erect and his feet resting on a surface so that his knees are bent at about right angles.

Elbow-Rest Height is the vertical distance from the sitting surface to the bottom of the right elbow. The measurement is taken with the subject seated erect, his upper arm hanging at his side and his forearm extended horizontally.

Eye Height, Sitting is the vertical distance between the sitting surface and the inner corner of the eye (internal canthus). The measurement is taken with the subject sitting erect, looking directly forward, with his feet resting on a surface so that his knees are bent at right angles.

Forearm-Hand Length is the horizontal distance from the tip of the right elbow to the tip of the longest finger. The measurement is taken with the subject sitting erect, his right upper arm hanging at his side, his forearm and hand extended horizontally.

Functional Reach is the distance from a wall, against which the standing subject's shoulders are pressed, to the tip of his thumb. This measurement is taken with the subject's right arm and hand extended horizontally and the thumb and forefinger pressed together.

Hip Breadth, Sitting is the maximum horizontal distance across the hips. This measurement is taken with the subject sitting erect, knees and feet together, with his feet resting on a surface so that his knees are at about right angles.

Knee Height, Sitting is the vertical distance from the footrest surface to the top of the right knee. This measurement is taken with the subject seated erect and his feet resting on a surface so that his knees are bent at about right angles.

Popliteal Height, Sitting is the vertical distance from the footrest surface to the underside of the right knee (popliteal area). This measurement is taken with the subject seated erect and his feet resting on a surface so that his knees are bent at about right angles.

Shoulder-Elbow Length is the vertical distance from the right acromion to the bottom of the elbow. This measurement is taken with the subject sitting erect, his right upper arm hanging at his side and his forearm extended horizontally.

Shoulder Height, Sitting is the vertical distance from the sitting surface to the right acromion. The measurement is taken with the subject sitting erect, both feet resting on a surface so that his knees are bent at about right angles.

Sitting Height is the vertical distance from the sitting surface to the top of the head. The measurement is taken with the subject sitting erect, looking directly ahead, and his feet resting on a surface so that his knees are bent at about right angles.